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LISTENER DESCRIPTIONS OF ISOLATED AND PATTERNED ACOUSTIC TRANSIENTS

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A three-phase experiment was conducted to assess listeners' ability to recognize and identify environmental acoustic sounds. The first phase was a free identification of ten short duration recordings of real-world events. The second phase was a free identification of five sequences composed of a subset of these ten transients. These sequences were intended to be meaningful, representing the sounds that could be

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produced by opening water or steam valves. The third phase was a forced identification of the ten transients using a checklist of descriptors. The results showed that while some types of sounds were identified correctly by most listeners, others were confused and rarely identified correctly. Several metallic sounds were often confused semantically even though they were quite distinct perceptually. The identification of patterns was found to depend upon both the salience of the individual sounds in the pattern and the semantic relationship between the sounds. Finally, it was demonstrated that signal processing errors can have perceptually meaningful effects. An error in processing one of the ten sounds produced a signal which was interpreted consistently by most listeners, but in a manner which had little semantic relationship to the actual event which had been recorded.

Acoustic transients can be characterized as brief sound bursts which do not repeat or continue over time. When they occur in isolation, they are difficult to detect and identify because they are unexpected. When there is appreciable background noise, techniques to reduce this noise may also filter out the transients, eliminating the possibility of detecting them. However, when the transients are imbedded in a sequence or pattern of other sounds, this context can be effective in aiding detection and identification. The surrounding elements can be used to generate hypotheses and expectancies for potential transients. A similar situation exists in the perception of speech. Warren (1970) has shown that when an individual word is replaced by a "buzz," listeners consistently reported hearing the missing phoneme. In this situation, the speech context promoted the expectation for the correct phoneme. This type of processing is referred to as top-down because the analysis of individual elements is guided by a global structure. The alternative is bottom-up processing in which the analysis of individual elements precedes and determines the development of general hypotheses. Both types of processing are involved in speech perception (Marslen-Wilson & Welsh, 1978), and evidence from our research indicates that both are important in the perception of non-speech sound patterns (Howard & Ballas, 1980).

There are many differences between these two processing approaches. The top-down approach is primarily inductive whereas the bottom-up is deductive. This contrasting orientation implies different strategies in identifying the isolated elements of a pattern. Using the top-down approach, the identification of a single

transient embedded in a pattern will involve a comparison between the unknown element and a hypothesized answer generated by the top-down structure. This is termed constrained classification, meaning that the potential categories or identities of the unknown element are restricted to a set that is plausible according to the structure driving the analysis. Theoretically, constrained classification requires a comparison between the potential categories and the unknown element. This comparison might involve a tallying and combination of similar and dissimilar attributes as proposed by Tversky (1977). It could also involve a similarity judgment between the unknown transient and prototypes which represent possible concepts. With this approach, the important determinant of identification accuracy will be the structure driving the analysis. If this structure is appropriate and well defined, then the hypotheses generated by it will be related to the correct solution. Our research has shown that semantic context will facilitate pattern identification only when it is appropriate. Otherwise, the effect is detrimental (Howard & Ballas, 1980).

Classification of individual transients is markedly different with bottom-up processing. Since there is no overall direction to the analysis of elements, free or unrestricted classification occurs, particularly with the initial elements of a pattern. Ultimately the unknown elements are compared to a possible solution, but preceding this comparison there is a memory search and retrieval process. This proceeds in a manner which suggests that a semantic memory network is being searched. For example, searches which might logically take longer because the interrelationship between the elements being

compared is remote do in fact require longer time to complete (Klatzky, 1975). A popular theory which is relevant to this type of search process is the semantic network theory proposed by Rumelhart, Lindsay, and Norman (1972). In their theory, the basic units of memory are concepts which are either objects, events, or classes of objects or events. Information is established in memory by specifying the relationships between concepts and by using former concepts to define new concepts. In essence, their model, and others that are similar, state that information in memory is grammatically structured, both semantically and syntactically. This semantic network represents the person's representation of accumulated knowledge. The data base consists of concepts that may have dictionary meanings. Those which do not have a dictionary definition are defined by others which do. This data base can be accessed, added to, or altered.

An active search through the network will trace the relationships through conceptual nodes until the appropriate concept is located. Of particular importance in the present context is the possibility that a search of the network may be initiated at an inappropriate location. In this case, the search either will be extended because a larger portion of the network must be traversed to reach the correct node, or will be fruitless because a route to the correct location cannot be found. Thus the accuracy of identifying an unknown element will depend upon the initial entry into the network and upon the structure of the network.

In an acoustic pattern context, the identification of unknown transients will depend upon the appropriateness of the semantic

network that is searched initially. With top-down processing, the network will be specified by some external entity, for example, the situational context. With bottom-up processing, the network will be determined by the data elements themselves. Thus, in order to predict the networks that are searched initially, it is important to understand which types of associations are prompted by isolated transients. Two general issues are raised when studying the specific networks that are elicited by an acoustic transient. First, to what extent are the associations appropriate or inappropriate semantic structures? The implications of this question for processing patterns of transients have already been discussed. The elicitation of an inappropriate network will hinder the correct perception of the pattern introducing delay and perhaps causing errors. The second issue is what is the strength and variability of the associations? The strength of an association will have an effect on the persistence of its semantic structures over time and in the face of conflicting perceptions. The variability of the associations across individuals may indicate whether population stereotypes exist.

Both of these issues are relevant to the specific transients that we have used in our previous research. We recorded the sounds of actual events to obtain the stimuli and thus there is face validity in their use. However, the degree to which they elicit specific semantic structures is an empirical question. Therefore, we conducted a simple recognition experiment in which listeners were asked to describe the events that could have produced the transient sounds.

Method

Participants. Twenty-eight students were recruited from Introductory Psychology classes as volunteers for this study. They received partial course credit for participation.

Stimuli. Ten transient sounds that have been used in our research program were chosen as the stimuli. These sounds were digitized using standard signal processing techniques with a 10-bit analog-to-digital converter at a 12.5 kHz sampling rate. These sounds included:

1. a hand clap
2. a metal hammer striking a metal wrench
3. a clang produced by striking a radiator
4. a water drip
5. an electric hand drill being started
6. water flushing down a drain
7. a 320 ms burst of random noise
8. an 82 ms burst of random noise
9. a squeaky radiator valve being opened
10. two pieces of wood struck together

Procedure. The experiment was conducted in three phases. In the first phase, the listener produced a free-response description of each sound. The stimuli were presented in a different random order for each listener. Each stimulus was presented three times and the listener was then given as much time as needed to describe the sound. The listener was asked to identify or name the sound as accurately as possible by describing an event which could have caused it. Thus rather than describe the acoustics of the sound, the listeners produced event descriptions.

In the second phase, a subset of the ten sounds was used to produce patterns of transients. Five patterns were chosen from the larger set of patterns that have been used in previous experiments.

The five patterns chosen were representative of the major varieties of patterns that have been used in our research. These patterns generally represent the sequence of events involved in opening a dripping valve and thus releasing water or steam. A description of each pattern and its intended interpretation is shown in Figure 1. Each pattern was presented three times after which the listener described a sequence of events that could have produced the pattern. The patterns were presented in random order.

In the third phase, the ten stimuli were again presented in random order--with three repetitions of each sound--and the listener identified the sound by choosing from a list of 20 names and terms. This list had been developed in pilot testing. Thus this phase involved a constrained-choice identification as opposed to the first phase which involved a free-response identification.

Results and Discussion

In the first phase of the experiment, data were gathered in a free identification format. These data were coded into categories established by analyzing and sorting the free responses. Two investigators developed preliminary categories for the first phase and then jointly reconciled their differences into one scheme. One of the investigators then coded all the responses. The second investigator checked these results for consistency. Sixteen categories were used (see Table 1). An examination of how each of the ten stimuli were classified into these categories revealed several interesting findings (see Table 2). First, there were several sounds that were consistently and correctly identified, indicating that these stimuli

Number	Transient Sequence	Intended Meaning
1	Drip Drip Open valve Flush	Opening a leaky valve causes water to drain.
2	Drip Drip Open valve Steam burst Pipe clang	Opening a leaky steam valve causes pipes to clang.
3	Open valve Open valve Open valve Steam burst Pipe clang	Three turns of a valve allow steam to pass causing pipe to clang.
4	Open valve Drip Drip Drip Open valve Flush	Opening a valve causes a leak; a second turn causes water to drain.
5	Open valve Drip Drip Open valve Steam burst Pipe clang	Opening a steam valve causes a leak; a second turn allows steam to pass causing pipes to clang.

Figure 1. Descriptions of the five transient patterns used in phase two.

Table 1

Free Identification Coding Categories

Code	Descriptions	
	Acoustic	Semantic
1	Clap/Pop	Hand clap, baseball hitting a glove
2	Screech/Squeal	Tire squealing, train brakes screeching
3	Hiss	Gas or steam escaping
4	Drip	Drop of water
5	Clank	Metal hitting metal
6	Flush	Water draining, water gurgling in a jug
7	Clink	Ceramic disk tapped, glass tapped
8	Whirr	Electric motor whirr
9	Knock	Hitting a wooden block
10	Crack	Gunshots, crack of a whip
11	Tap	Pencil being tapped
12	Scrape	Metal scraping against metal, wood against wood
13	Zip	Match being lit
14	Clang	Tin can being dropped
15	Skip	Needle skipping or scratching on a record
16	Miscellaneous	

Table 2

Free Identification Results

Free Ident Category	Stimuli									
	Hand Clap	Metal Clank	Radia. Clang	Water Drip	Elec. Drill	Water Flush	Noise 320ms	Noise 82ms	Open Valve	Wood Knock
Clap	10	0	0	0	1	0	0	0	0	2
Screech	0	0	0	0	2	2	0	1	11	0
Hiss	0	0	1	2	2	1	20	15	1	0
Drip	0	0	1	21	0	0	0	0	0	1
Clank	0	10	11	0	0	0	0	0	0	3
Flush	1	0	0	0	0	13	0	0	0	0
Clink	0	7	1	0	0	0	0	0	0	2
Whirr	0	1	1	0	0	1	0	1	2	0
Knock	0	1	0	0	1	0	0	0	0	16
Crack	2	0	0	0	0	0	0	1	0	2
Tap	2	1	0	0	0	0	0	0	0	1
Scrape	1	0	1	0	7	5	0	0	3	0
Zip	1	0	0	0	3	0	0	4	0	0
Clang	0	5	6	0	0	0	0	0	1	0
Skip	1	0	0	0	9	0	2	3	4	0
Misc	10	3	6	5	3	6	6	3	6	1
Total	28	28	28	28	28	28	28	28	28	28

exhibit a strong population stereotype. The "drip" and the 320 ms noise stimulus were most consistently identified, followed by the "wood knock," the 82 ms burst of noise, and the "water flush." Note that shortening the burst of noise reduced the consistency with which it was identified as a burst of steam or air. The second finding of interest is that the two percussive metallic stimuli were confused semantically. The coding for the metallic percussion sounds included three possible categories, "clink," "clank," and "clang," representing progressively greater resonance or reverberation. Typical events for these three categories were metal striking ceramic or glass for a "clink," metal striking metal for a "clank," and a tin disk dropping onto the floor for a "clang." The results indicated that listeners confuse these categories because the two metallic stimuli were described inconsistently as all three types of sounds. This was particularly evident for the stimulus produced by striking a hammer against a wrench. The implication of this finding is that it may be necessary to train listeners on the meaning of acoustic descriptions even if the differences between these descriptions are self-evident in their articulation.

The final result of interest in this phase is that only two stimuli were described in a manner which was inconsistent with the actual events which produced them. One of these sounds was a valve opening which sounded like a squeal or screech and was thought to be caused by tires squealing, trains braking, a tape being rewound or other events not related to a valve opening. Although the interpretations were acoustically consistent with the valve opening

they were not semantically related to it. Descriptions of the other stimulus which was mislabeled were neither acoustically nor semantically consistent with the recorded event. This stimulus was produced by starting an electric hand drill, but because of digitizing errors, it sounded more like a needle skipping across a phonograph record than the "whirr" one would have expected. The mistake was not discovered until midway through data collection, and so the stimulus was not changed. Interestingly, the listeners' descriptions of this artificial stimulus were consistent, being either of the record skipping type or of an object scraping against a coarse surface, such as a fingernail against a blackboard. Thus, inadvertently we found that signal processing errors can have perceptually meaningful effects. In this situation, the error was substantial and so also was the result. However, even subtle errors can produce unintended perceptual errors.

The coding for the second phase of the experiment also required an analysis of free responses. To code these data, general themes were defined to represent the actual scenarios used by the listeners to describe the patterns. These themes represented the broad subject matter of the pattern description. For example, if the pattern were described as a leaky faucet being opened that caused water to flush down a drain, it would be coded as a water-related theme. Six thematic categories were used. Three other categories were added to code miscellaneous themes, multiple themes, and descriptions which were not thematic but rather acoustic. The results for this phase indicated that three subgroups of the five patterns were similarly

interpreted (Table 3). The first subgroup included patterns one and four which were generally interpreted using water themes. These two patterns included a series of water drips and ended with a valve opening and a water flush. These water themes were probably elicited by the drip stimulus which was strongly associated with water, and reinforced by the water flush ending the pattern. In this context the screech-like sound was interpreted as a valve or faucet being opened.

The second group included patterns two and five which either were interpreted as machinery sounds or were not interpretable at all. These two patterns included a water drip, a burst of steam and a pipe clang. Apparently these elements either were not integrated or were interpreted as a cacophony of machinery. The intended theme for these patterns was that a leaky radiator pipe was being opened. However, the listeners generally did not produce a water-related theme.

The last subgroup consisted of pattern number three which included a valve opening, a burst of steam and a pipe clang. Listeners interpreted this pattern according to three themes, machinery, auto, and miscellaneous. The valve opening was a screech-like sound and was often interpreted as tires squealing. Thus an auto theme was often generated. The burst of steam and the pipe clang also prompted a general machinery theme as they did with patterns two and five. Finally, unusual themes were prompted by this pattern as for example the description that "something was scraped, deflated and dropped on the floor."

Overall, the results of this phase indicated that coherent patterns of isolated transients can be interpreted meaningfully and

Table 3

Thematic Classification of Patterns in Phase 2

Themes	Patterns				
	1	2	3	4	5
Water	13	3	1	14	4
Auto	6	3	7	2	3
Machinery	2	7	6	3	7
Battle	0	0	3	0	2
Music/Percussion	2	3	1	1	0
Misc	2	3	6	3	4
Multiple	0	3	1	2	2
None	3	6	3	3	6
Total	28	28	28	28	28

that the specific interpretation will be directed by both the salience of the individual elements--as for example the drip and flush--and the relationships among the elements.

The results of the third phase in which constrained identification was required were used to assess the reliability of the data from phase one. Two general findings are worthy of note. First, all but two of the individual transient sounds (valve opening and electric drill) were identified in a manner which was consistent with the actual event which produced the sound (see Table 4). This result verified the analysis of phase 1. The second result of note is that consistency of interpretations across the two phases varied for the ten stimuli in a manner similar to the unanimity of the interpretation within each phase (see Table 5). For example, of all the stimuli, the water drip and the long burst of noise were interpreted most consistently across the two phases, the longer burst of noise was more consistently interpreted than the shorter burst, and the two metallic percussion stimuli were not consistently interpreted across the two phases. These results show that the unanimity of an association for a isolated transient will indicate the consistency and stability with which it will be interpreted. These results also suggest that the labels we provided listeners in our previous experiments (Howard & Ballas, 1980) were generally appropriate for the sounds.

The implications of the two mislabeled stimuli were discussed above. To amplify on that discussion, it is apparent that listeners in our previous experiments may have associated the valve opening stimulus with an inconsistent semantic structure and consequently it

Table 4

Constrained Identification Results

	Stimuli									
Checklist	Hand Clap	Metal Clank	Radia. Clang	Water Drip	Elec. Drill	Water Flush	Noise 320ms	Noise 82ms	Open Valve	Wood Knock
Bang	0	0	0	0	0	0	0	0	0	1
Clank	0	7	7	1	0	0	0	0	0	2
Steam hiss	1	0	0	1	2	0	23	15	0	0
Squeaking door	0	0	0	0	0	0	0	0	1	0
Valve turning	0	1	0	0	5	3	0	5	2	0
Water drop	0	1	0	24	1	0	0	2	0	0
Hammer hitting a nail	3	15	3	0	0	0	0	0	0	2
Jet	0	0	0	0	2	0	3	2	0	0
Knocking on a door	4	0	0	0	2	0	0	0	0	2
Water flushing	0	0	0	0	0	13	0	0	0	1
Wood hitting wood	5	1	0	2	1	0	0	1	0	20
Electric drill	1	0	0	0	0	1	2	0	9	0
Car engine	0	0	0	0	0	1	0	0	2	0
Water splashing	0	0	0	0	1	3	0	0	0	0
Screech	0	0	0	0	0	1	0	1	9	0
Sawing a board	0	0	0	0	6	3	0	0	1	0
Fingernail on a chalkboard	0	0	0	0	7	3	0	2	3	0
Clap	14	0	0	0	1	0	0	0	0	0
Telephone ringing	0	0	0	0	0	0	0	0	0	0
Clang	0	3	18	0	0	0	0	0	1	0
Total	28	28	28	28	28	28	28	28	28	28

Table 5

Correct Identifications Within and Between Phases 1 and 2

Stimuli	Phase 1	Phase 2	Joint
Clap	10	14	8
Clank	10	22	9
Clang	6	18	4
Drip	21	24	21
Flush	13	13	10
380 ms noise	20	23	17
82 ms noise	15	15	10
Open valve	11	9	6
Wood knock	16	20	14

Note: The drill stimulus was not included in this analysis.

may have interfered with the water and steam structures that we intended to suggest. In particular, when this sound was combined with the metallic clang in patterns two, three, and five, the listeners in this study were more likely to produce machinery or auto related themes than water themes. Thus it is important to understand the semantic network elicited by an isolated transient in order to predict how a pattern which includes it will be interpreted. For example, we would predict that if a listener correctly identified individual water sounds, that individual would be likely to generate a water theme to describe a pattern which contained those sounds.

In order to assess this hypothesis, we compared the number of correct water identifications in phase one to the number of water themes generated in phase two. For each listener, this meant generating two new variables, one which represented how many water transients were correctly identified, and a second variable representing how many water themes were generated to describe the patterns. The results indicated little relationship when all five patterns are included, but a significant positive relationship when only patterns 1 and 4 are analyzed (see Table 6). These two patterns were the only ones which were generally described with water themes. These results mean that the interpretation of a pattern depend upon the identification of the elements and the semantic relationship between these elements. Correctly identifying water sounds will not guarantee the production of water themes for patterns which also included other types of sounds as well. The generation of an overall relationship must depend upon a context which can incorporate all the

Table 6

Water Transients Identified and Water Themes Generated

Patterns	Themes	Number of Water Transient Identifications 1	2	3	4
All					
	Water	4	1	12	18
	Other	21	9	43	32

$\underline{X}$ =5.80 .20< $\underline{p}$ <.10

Patterns	Themes	1	2	3	4
1 & 4					
	Water	2	1	10	14
	Other	8	3	12	6

$\underline{X}$ =7.92 .05< $\underline{p}$ <.02

individual elements. In this study, the context was produced by each listener. However, it can be defined by other persons or other events. In our previous research, we have shown that a semantic context provided with instructions to the listener can enhance pattern recognition, but only if the patterns are consistent with the context. The results of the present study substantiate this finding and show that it applies in situations where the listener is free to define the stimuli and the context.

There are several implications of these results for passive sonar performance. First, it is important to understand the semantic context the sonar operator is using. Mackie (1974) has shown that an externally provided context can influence isolated transient identification and we have shown that instructions can influence the perception of transient patterns (Ballas & Howard, 1980; Howard & Ballas, 1980). The present results show that individual transients will generate a semantic context which in turn will influence the perception of the pattern in which they are embedded. A second implication of this study is that we cannot assume that simple verbal descriptions of acoustic transients will be interpreted correctly. This was indicated by the confusions among the metallic categories in phases 1 and 2. Finally, the last important implication is that signal processing errors can have potentially meaningful effects on transient perception. Inadvertently, we found that a transient which was distorted by incorrect digital sampling was interpreted meaningfully by most of the listeners. The errors may be sporadic as in the present case or systematic as, for example, in the case of

digital sampling with a rate too slow to capture the sharpness which distinguishes some metallic sounds from their wooden equivalents. The operational implications of meaningful distortions are important enough to warrant further research.

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